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ASSESS THE FEASIBILITY OF A PROCESSING PLANT METHOD OF RETTING FLAX STRAW IN SASKATCHEWAN

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Final Report

Assess the Feasibility of a Processing Plant Method of Retting Flax Straw in Saskatchewan

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Table of Contents

Page

1. Summary 1

2. Technical Report 3
   - 2.1 Introduction 3
   - 2.2 Objectives 3
   - 2.3 General Description 3
   - 2.4 Scope of Test 4
   - 2.5 Results and Discussion 5

3. Personnel 25
   - 3.1 PAMI Manpower Supplied 25

..

5. Equipment 27

6. Project Photos 28

1. Summary

The goal of this project was to define a retting process suitable for implementation at a full-scale plant level. It was believed that with proper management of humidity, temperature, and wetting/drying cycles, this could be achieved. It was intended that the parameters and procedures necessary for retting loose or baled straw be the basis for scale-up model. Testing failed to provide the "ideal" procedure for retting.

Tests designed to explore the effects of the aforementioned parameters revealed few quick answers but raise many unexpected challenges. Ultimately, not enough unknowns were answered to enable formulation of a definite procedure to be used as the basis for retting plant design. However, much was learned of the dynamics involved. The tests performed explained the influence of certain aspects and offered insight into the requirements for future research.

Tests showed that time played a critical role in the amount of retting. Once the retting process was started, the level of retting steadily increased with time. To reach a suitable level took up to 14 days. Efforts to reduce the process to a shorter period through controlling conditions yielded incomplete retting.

Wetting was also determined to be a crucial factor. First, suitable water quality was required so as not to interfere with the survival of the microbial retting agents. This required pH adjusted, untreated, non-sanitized water. Second, thorough and even exposure to moisture was identified as a priority for initiating and maintaining retting. Tests suggested approximately 2 L of water per kg of straw was needed. High humidity conditions were insufficient to keep the straw wet enough for retting. Without sustaining proper moisture levels, retting would not progress.

In relation to the importance of wetting, drying proved equally, but oppositely, important. Introducing a drying interval impeded the retting process. As well, it also created the proper conditions for mould to establish. Tests showed that drying was only useful for halting the process and not for enhancing the retting rate or completeness.

Tests involving monitoring and controlling temperature indicated that maintaining temperature within a certain range would positively affect retting progression. Optimizing temperature to 35°C improved retting performance marginally over room temperature. Although, attention needs to be given to avoid temperature extremes at either end of the gradient.

Tests were initially carried out on small-scale batches of loose straw and then progressed to attempts using whole round bales. Results indicate some potential for retting whole bales, but the practicality was not conclusively proven. Certain challenges that were not present in loose straw tests, such as even moisture distribution, need further investigation if bales were to be used.

Little progress was made on accelerating retting beyond providing a suitable environment for retting. As a result, it was impractical to explore how to lay out a facility for retting flax on a commercial basis. This is not to say that the project failed. Considerable knowledge was gained concerning the factors affecting retting and which procedures work. The information in this report will serve as a strong foundation for understanding the basics of retting. It has also more clearly defined the areas that require further experimentation before any consideration should be directed at designing a plant operation.

2. Technical Report

2.1 Introduction

Saskatchewan weather does not provide adequate humidity and temperatures to ret flax straw on a consistent basis, but field weathering is a needed part of retting. Retting straw in water anaerobically has secondary environmental implications, as the water requires aeration and treatment before discharge. Retting straw in field with irrigation or rolling prior to over wintering has been shown to improve retting, but results are not consistent.

A process that could be used in a "plant" environment is needed to provide a consistent supply of quality retted flax straw. In this project, various methods of wetting and drying flax straw were tried and monitored when using both baled and loose straw. Different methods were used to start, control, and stop the retting process and to prevent the growth of mould.

2.2 Objectives

The objectives of this project were to try to discover and develop a procedure to ret flax straw indoors in an industrial plant environment. The first target was to determine the most effective wetting and drying combination that produced suitable retting while preventing mould growth.

2.3 General Description

Tests were done in the Crops Processing Development Centre (CPDC) at PAMI in Humboldt. Much of the testing was done in the environmental chamber within the CPDC. This chamber is a large, insulated, well-sealed room that has equipment for heating, cooling, and controlling the humidity within the room. A hot glycol coil and fan unit were used to provide heat into the room. When high humidity was required, an air assisted atomizing nozzle was used to introduce moisture into the air.

During discussions with Biolin Research Inc., retting water quality was discussed and they advised against the use of tap water, as the chlorine would likely inhibit biological growth. They suggested that it would be better to use water from a slough or lake and adjust the pH to less than 6.8. Upon this advice, water for this project was obtained from Stoney Lake, a fresh water lake located south of Humboldt. The pH was measured using litmus paper and adjusted using either sulphuric acid or swimming pool treatment chemicals. To avoid introduction of any anti-bacterial chemicals into the water, a steel bathtub with an enamel coating was used to hold water for individual tests.

Initial assessment of retting was based on visual inspection, but Biolin Research Inc. ultimately determined the level and consistency of retting based on a standardized test procedure they had developed for this purpose. This procedure involves analysis of at least 30 sub-samples from each sample evaluated. Retting completeness is indicated by a number from 0.0 to 3.0, with 3.0 representing a fully to over retted condition. They have determined that for further commercial processing, retted straw needs to be around 2.5. Consistency and evenness of retting is represented by another value referred to as the percentage difference in coefficient of variation (cv) between sub-samples. The lower the percentage, the more evenly samples have been retted.

2.4 Scope of Test

The first tests were done by hanging wire baskets of loose flax straw in the environmental chamber. The flax straw in the baskets was dipped into the bathtub full of water for two minutes. The basket of straw was then hung in the environmental chamber and the humidity was adjusted and held at a target setting for the duration of the test. A fan circulated air within the room. For some tests, the baskets of straw were dipped back in the water at specified intervals for a short period.

The next tests were similar to the first in that the straw was dipped in water and then maintained at a high humidity in the room. However, in these tests, the straw was placed in a metal tube through which air was drawn to ensure that the high humidity air was forced to flow around the straw.

Another series of small-scale tests was done by placing a layer of loose flax straw on top of a screen and periodically sprinkling it with water to keep it wet. The first of these tests was done on a small section of screen (1.5 ft and 3.5 ft) attached to a wooden box. A small fan was used to draw air through the straw to dry it after the wetting portion of the test was complete.

Following these small-scale tests, a conditioning trailer was used to duplicate these procedures on a larger scale. This trailer had a screened floor and a fan, which draws air down through the screen and layer of straw lying on top of it. In the first tests, a round bale of flax straw was partially unrolled leaving a mat of straw approximately 12 in. (30 cm) thick on the screen. A pump charging a large hose was used to initially wet the straw. In subsequent tests lawn sprinklers on a timer were used to wet the straw. This provided for more controlled and repeatable wetting cycles.

Tests were also done using a round bale set on end. For these tests, a smaller lawn sprinkler was used to wet the bale periodically. Finally, tests were carried out where the round bale was dipped into a tank of water to thoroughly wet it, and then it was lifted out and left to drip-dry for a set time. This dipping/drying process was repeated numerous times per day.

Tests involving elevated temperatures were done in the environmental chamber and ambient temperature tests were done in the CPDC. When a test run was complete, the fan was used to draw air through the straw. For tests involving whole bales, the bale was wrapped in plastic tarps to ensure airflow through the bale during drying.

2.5 Results and Discussion

2.5.1 Test Procedures

Initial Tests: The first tests in this project explored the use of high humidity to maintain a favourable environment for retting flax straw. The basic test procedure required the straw bundle to initially be dipped in water to induce the conditions for retting; it was then placed in a high humidity environmental chamber for a specific time. Variations to this procedure included adjustments to relative humidity (RH), air movement, and the drying interval.

Initially, the environmental chamber was set to maintain an RH of about 80%. Two bundles of flax straw were dipped into the tub of pH-adjusted water and left suspended in the humidity chamber. Retting appeared to have started after a few days, but there was concern that moisture distribution throughout the bundle was irregular. The bundles contained straw that was only partially retted, while others showed no evidence of beginning to ret.

Next the same process was slightly changed and this time the flax straw was suspended so that the bundles were spread out into a thinner layer (approximately 1 in. thick). It was hoped that this would provide more thorough exposure of the straw to moist air and improve retting. However, after a few days the straw appeared to have dried, and the retting process had stopped. It was suspected that 80% RH was not high enough to keep the straw wet enough to be conducive to retting. The RH setting in the environmental chamber was adjusted to 90% and new bundles dipped and left to ret.

After a week it was noted that, again, the samples had become too dry. It was hoped that if the humid air was forced to pass through the straw mass, this might maintain straw moisture for a longer time. This led to the dipped straw bundles being placed in an air duct tube (approximately 6 in. in diameter) with a fan attached to one end to pull the humid air through. However, this did not produce any consistent retting results. **Table 1** displays the results of initial tests.

Table 1. Test 0 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 0	80% RH 7days - #2	2.13	31.0%
Test 0	80% RH 7days - #5	1.80	37.6%
Test 0	80%/90% RH - initial	0.67	55.4%
Test 0	80%/90% RH 22 days - #2	2.12	47.7%
Test 0	80%/90% RH 22 days - #5	1.09	65.2%
Test 0	90% RH 4 days - #1	0.66	48.3%
Test 0	90% RH 4 days - #4	2.13	35.1%
Test 0	90% RH 8 days - #1	1.63	45.9%
Test 0	90% RH 8 days - #4	1.50	54.6%
Test 0	90% RH 15 days - #1	1.10	68.9%
Test 0	90% RH 15 days - #4	0.71	53.0%
Test 0	90% RH Initial Tube	1.07	65.2%
Test 0	90% RH Tube 7 days	1.44	46.8%

Contrary to what was expected, drawing humid air through the flax straw appeared to dry out the straw faster, thus inhibiting the retting process. The 90% RH Tube samples exemplify this. It was also noted that many of the Test 0 samples showed indications of mould growth, which is damaging to the retted flax fibre's end quality. Visual assessment of the flax straw found that some straw contained the mould before retting. As well, some of the straw appeared to have been partially retted previously, casting some doubt on the effectiveness of the treatments.

From these observations, it was determined that the moisture level on the flax straw must be maintained higher than was possible through humidity alone, and therefore further testing would have to incorporate more direct wetting procedures.

Next Stage: For the next phase of testing, the methodology of using RH to sustain productive retting conditions was abandoned. A new procedure to maintain flax straw moisture was adopted. This procedure involved repeatedly wetting the straw over a set period, and then drying to halt the process. To do this, an aeration screen was employed. On small-scale tests, a wooden box with aeration screen on the top and a fan to draw air through was used (**Figure 1**). For larger scale tests, a trailer designed with the same features was used (**Figure 2**).

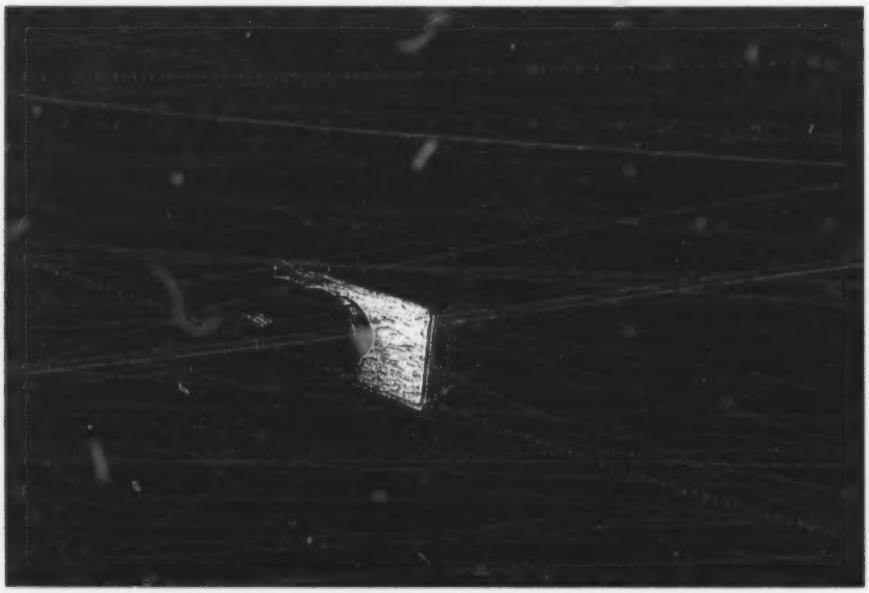

Figure 1. Aeration Box.

Figure 2. Aeration Trailer.

The first test of the new wetting strategy utilized the small-scale aeration box. A layer of flax straw was spread on top of the screen and thoroughly soaked with water. This straw mat was then rewetted throughout the day. The rewetting interval was adjusted so that the straw did not dry out between wettings and there were still water droplets evident on individual straws. The timing for wetting worked out to be approximately every half hour to hour during the day. At night, the straw mat and box were wrapped with plastic to retain moisture and minimize evaporation losses. After three days of this treatment, wetting was ceased and the fan started. The fan pulled air down through the straw mat, wicking away residual moisture to the point where retting no longer occurred. This drying typically lasted a few hours. Results from this test were very promising, indicating a statistically significant different level of retting between the initial sample of unretted straw and the sample from the test. These results are shown in **Table 2**.

Table 2. Test 1 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 1	Before Sample	0.50	91.0%
Test 1	After Sample	2.57	22.7%

The flax straw sample was rated at 2.57, with 22.7% difference in cv. This test, Test 1, turned out to be one of the most complete and most consistent retting trials performed.

Test 2 was carried out using the same protocol as for Test 1, except that instead of halting retting after three days, it was dried overnight after two days. Then the wetting cycle was repeated for two more days, before drying. Test 2 findings are displayed in **Table 3**.

Table 3. Test 2 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 2	Before Sample	1.17	86.0%
Test 2	After Sample	1.17	62.0%

Results from this test illustrate that adding a drying cycle did nothing to enhance the retting process, as the level of retting was identical to the initial sample. Also, the consistency of retting within the sample was practically unchanged.

On a larger scale, Test 1 was repeated using the aeration trailer. During the day, wetting was carried out on roughly an hourly basis, and at night the trailer was covered with plastic tarps. Test 3 lasted three days, the same as Test 1. The flax used for this trial was taken from round bales collected in the fall of 2003.

Meanwhile Test 4 was conducted on the small-scale platform. For this test as well, flax straw originated from a round bale. Test 1 protocol was repeated with regular wettings for three days. Although similar to the previous tests, a new dynamic was added by using recycled water to wet the flax straw mat. To accomplish this, the water runoff from the initial wetting was collected and used to rewet the straw at each wetting interval. Tests 3 and 4 were done concurrently to ascertain whether the size of the test bed, small-scale box, or large-scale trailer had an effect on retting productivity. Water was reused on Test 4 to verify if this practice had an effect on the retting process. Retting results contained in **Table 4** display the findings of Tests 3 and 4. Two samples from each test were taken in efforts to increase the level of confidence through repetition.

Table 4. Test 3 and Test 4 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 3	Before Sample	0.23	184.4%
Test 3	After Sample I	0.13	195.3%
Test 3	After Sample II	0.23	175.6%
Test 4	After Sample I	0.18	231.9%
Test 4	After Sample II	0.15	178.3%

Retting results of Test 3 (large-scale) compared to Test 4 (small-scale) showed no appreciable differences. This verified that the size of the test bed had no effect on the progression of retting in the time allotted. It also indicated that recycling the water from the wetting cycles did not bear any adverse consequences. However, in this case, neither of the tests generated any conditions that promoted retting.

The next test procedure utilized the aeration trailer. For Test 5, two trials were set up in the trailer; one in the front and one in the back. Again, the water from the initial wetting was reused in the subsequent wettings (supplemented with fresh water as needed). After two days, the drying fan was turned on overnight. Half of the trailer was covered with a tarp and the other half was left open. This procedure enabled samples to be taken that represented:

- (After I) two days wet then dried
- (After II) two days wet, then dried, then two days wet
- (After III) four days wet, then dried

Progression of retting in Test 5 is presented in **Table 5**.

Table 5. Test 5 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 5	Before	0.10	275.4%
Test 5	After I	0.23	192.8%
Test 5	After II	0.77	94.9%
Test 5	After III	1.02	73.6%

The results shown in **Table 5** suggest that level of retting increased with time. Both After II and After III samples showed a marked increase in retting compared to the Before sample. Comparing After II and After III samples also indicated that, since both samples were wet for a total of four days, a break in the wetting cycle using an overnight drying interval (After II) produced no improvement in retting. These results supported the idea that time was a critical factor in the retting process.

Test 6 also used the aeration trailer test bed. A straw mat was laid on the trailer floor and wet repeatedly (reusing initial water) over the course of a few days. Samples were taken at the end of each day and dried on the small-scale dryer. This test lasted three days, yielding three samples, each representing a one day increase in wetting duration. Time again proved again to be a consistent factor in the retting process, as shown by the results in **Table 6**.

Table 6. Test 6 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 6	Before	0.17	198.3%
Test 6	After I	0.20	192.5%
Test 6	After II	0.55	99.4%
Test 6	After III	0.83	91.0%

In the **Table 6**, the samples are listed chronologically, with After I being taken following one day of wetting through to After III which was sampled upon completion of three days of wetting cycles. An obvious trend is that increased retting appears to be directly related to time. Both samples, After II and After III, were statistically more retted than the Before sample. What isn't quite as obvious was the slight tendency of the percentage difference in cv's to decrease over time. This number suggests that as the level of retting increased, the samples were also becoming slightly more evenly retted. Although the results were encouraging, it must be noted that none of the samples were retted to required levels for practical purposes.

Tests 5 and 6 attempted to "fast track" the retting process (compared to traditional field retting) through a more condensed, intensive methodology. Based on those results, the goal of Test 7 was to define how much time was needed for complete retting. Therefore, Test 7 replicated Test 6 but continued for nine days. Samples were taken and dried after seven, eight, and nine days. For Test 7, an automatic watering system was implemented. This allowed regular and consistent wettings for the majority of the test, during both day and night. The watering interval was set to three minutes every hour and a half. **Table 7** shows the results from Test 7.

Table 7. Test 7 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 6	Before	0.17	198.3%
Test 7	Sample I (after day 7)	1.07	76.6%
Test 7	Sample II (after day 8)	1.27	58.4%
Test 7	Sample III (after day 9)	0.65	57.7%

Test 7 did not establish the relationship of time and level of retting completeness as clearly as was initially hoped. The straw for Test 7 was taken from the same bale as Test 6, so the results should be comparable to the Before sample for an indication of retting success. The first two sample results substantiated the basic relationship between the level of retting and time. Sample III unexplainably exhibited a decrease in retting from earlier samples. As it is theoretically impossible for the retting process to be reversed, the decrease in level of retting between Sample II (Day 8) and Sample III (Day 9) is suspected to be the result of sampling variability.

Although the results of Test 7 may appear somewhat disappointing when they are compared to Test 6 findings, since the three tests were conducted under similar conditions, they are quite encouraging. The increased level of retting after seven or eight days was notably higher than after one, two, or three days and most definitely higher than the Before sample. This continues to show that the time and level of retting relationship remains somewhat consistent.

Based on the results of Test 7, that more retting took place as time went on (compared to Test 6), the next test was aimed at optimizing retting time by incorporating other factors. It was thought that retting might be assisted by favourable temperature conditions. This led to Test 8 being done in the environmental chamber where temperature could be monitored and controlled. Through consultation with Biolin Research Inc., it was learned that 35°C was an ideal temperature for the bacteriological population. The temperature was set to this target, and the automatic watering system was turned on for three minutes every hour and a half. The test lasted seven days. **Table 8** contains the results.

Table 8. Test 8 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 6	Before	0.17	198.3%
Test 8	Day 2	0.95	69.6%
Test 8	Day 3	1.02	59.9%
Test 8	Day 4	1.10	64.7%
Test 8	Day 5	1.28	71.4%
Test 8	Day 6	1.83	44.9%
Test 8	Day 7	1.70	40.6%

The level of retting increase through to Day 7, and the uniformity improvement as the percentage difference in cv indicates, reinforces the trend found in the previous tests. Test 6 Before sample was again used as the benchmark. It appeared that the higher temperature promoted retting based upon the difference between seventh day results of Test 7 and 8. In Test 7 after seven days the level of retting was assessed at 1.07, while in Test 8 it was stated at 1.70. This suggests that the temperature conditions of Test 8 assisted in retting.

Upon completion of Test 8, it was concluded that with what was known of the parameters affecting flax straw retting, that a larger sample should be tried using a round bale. Test 9 involved the same procedure as Test 8, but instead of a mat of loose straw, a whole round bale (set on its end) was used. The temperature setting remained at 35°C; however, the watering interval was changed to approximately 10 minutes every hour and a half. The wetting interval was modified part way through the test, as it appeared that the bale was not wet enough to promote retting. The time was adjusted so that about 12 minutes of every hour was spent watering.

In an effort to monitor the progress of retting inside the bale, attempts were made to collect a core sample. A coring tube previously used to gather samples from cereal straw bales was used. This method of sampling proved unsuccessful. The flax straw had a tendency to catch and wrap on the coring device, preventing penetration of the bale. Observations of retting proficiency had to wait until completion of the test.

As the testing continued over 11 days, it was noted that the internal bale temperature of 40 to 45°C was markedly higher than the ambient temperature of 35°C. This posed a problem, as temperatures greater than 40°C could be fatal to the microbial population responsible for retting. The heat produced by the microbes at work, combined with the relatively high ambient temperature, was too much to sustain a suitable living environment for the retting agents. The temperature was reduced to approximately 28°C, with the goal of maintaining an internal bale temperature of 35°C.

After 11 days, drying commenced using the fan on the aeration trailer. Initially the bale was left uncovered, but it was found that air was being drawn from the sides of the bale, rather than down through it from the top. Therefore, the bale was wrapped with plastic leaving only the top (flat) side open (**Figure 3**). The unused portion of the trailer deck was also closed off to make certain the full capacity of the fan was utilized to pull air through the bale.

Figure 3. Bale Wrapped in Plastic Tarp for Drying.

Table 9. Test 9 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 6	Before	0.17	198.3%
Test 9	Whole Bale	2.00	45.0%

No initial sample was taken for Test 9, but comparison to the Before sample from Test 6 was appropriate, as the straw was from the same batch of bales. The result in **Table 9** shows the level of retting to be 2.00, which would appear relatively successful, especially in contrast to the Before sample rated at 0.17. What it did not reflect was the white and brown mould that was abundant throughout the bale.

Although the percentage difference in cv at 45% indicates marginally even retting in the sample, this was not true for the entire bale. Visual inspection of the bale revealed channels that were quite retted where the water had drained through, and other sections that seemed to be free from retting. Obviously, although a reasonable attempt was made to retrieve a representative sample for analysis, this seemed to have been unsuccessful.

The dynamics of a whole bale had displayed the shortcomings of the system in place for retting. The wetting procedure did not account for the changes in density amongst the layers within the bale, which prevented even distribution of and exposure to the water. This created wet and dry pockets within the bale, allowing some spots to ret while others remained too dry to ret, but a perfect environment for mould to establish as is evident in **Figure 4**.

Figure 4. Mouldy Straw from Bale in Test 9.

The lessons learned from Test 9 were incorporated into a new treatment for Test 10. Again, a whole round bale, on its end, was used. This time though, the procedure concentrated on ensuring sufficient and even wetting throughout the bale. To do this, the automated sprinkler system was eliminated, and a new approach was developed. The bale was suspended by a series of slings and periodically submerged in a vessel of water (**Figure 5**). This procedure made certain that the whole bale was exposed to moisture.

Figure 5. Wetting Method Used in Test 10.

The bale was submersed up to four times per day, from 15 minutes to 1 hour, for the duration of 11 days. At the end of the stated interval, the bale was set on the aeration trailer, wrapped in tarps, and air drawn through it.

Table 10. Test 10 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 10	Whole Bale Small Sample	1.90	23.3%
Test 10	Whole Bale	1.22	44.1%
Test 10	Whole Bale (Core)	1.57	34.3%
Test 10	Whole Bale (Midway)	1.62	36.9%
Test 10	Whole Bale (Outer)	1.10	51.2%

Test 10 was sampled in numerous ways. The Dipped Bale Small Sample was taken immediately before the drying was started. The straw sample was collected from the bale and dried on the small-scale aeration box. This was done to establish whether mould was present prior to the six days spent drying the bale. The small sample showed mould had not developed.

Other samples were gathered following the bale's drying period. They were intentionally taken from different locations within the bale (core, midway, and outer), so that comparisons could be made for consistency and level of retting. Also a conglomerate sample was put together. The results gave the impression that retting tended to increase towards the centre core of the bale. However, the manner in which the samples

were collected was not sophisticated enough to ensure the accuracy of this. More precision in defining the sample locations within the bale would be needed to enable accurate conclusions to be drawn. As well, the fact that the Whole Bale Small Sample was taken from roughly the same location as the Whole Bale Outer Sample but yielded considerably different results, which causes some concern as to what amount of sample variability is reasonable.

Test 11 was done specifically as a benchmark for the other tests, solely to indicate what was attainable. It was done as a small batch in the bathtub. The straw was left completely submerged for the duration of the test, which was 14 days. Samples were taken and dried on days 7 through 14. This procedure was believed to imitate the way retting is performed in other commercial applications. The challenge for this method, however, is finding an acceptable way to deal with the effluent water and to adapt such a procedure to a commercially viable plant operation.

Table 11. Test 11 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 11	Day 7	0.62	34.9%
Test 11	Day 8	0.98	68.7%
Test 11	Day 9	2.40	20.0%
Test 11	Day 10	2.42	19.7%
Test 11	Day 11	2.08	21.0%
Test 11	Day 12	2.57	13.3%
Test 11	Day 13	2.52	16.9%
Test 11	Day 14	2.67	13.3%

The results of Test 11 show underwater retting as one of the most successful tests performed. Retting progressed steadily, indicating extremely positive numbers from Day 9 on. No other tests came close to matching this performance. Despite the effectiveness of this method, the possible environmental concerns associated with the wastewater could present challenges that make a commercial plant impractical.

2.5.2 Time

Retting: Time proved to be a major factor in retting. It is likely one of the most critical aspects of retting. Without sufficient time for the process to develop and mature, optimizing other parameters like temperature, humidity, and wetting and drying intervals will not likely yield properly retted straw. This was confirmed through a number of tests, which showed that the samples were consistently more retted as time went on, but if halted too soon, retting was left incomplete. The effect of time on the retting process can be seen in **Figure 6.**

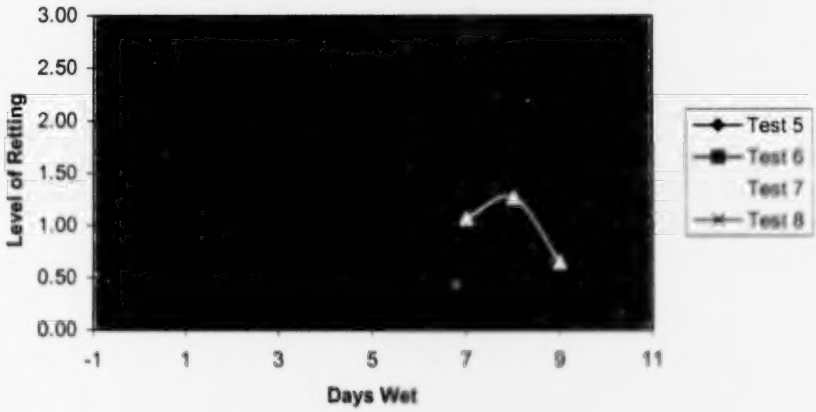

Figure 6. Retting Progression Over Time.

Except for Test 7, which supports the trend except at the end, all three tests trend towards increased retting with time, but because the timeline was cropped short, the process was incomplete. Efforts in these tests to condense the process into a shorter time frame failed. Exact time needed to complete retting is unknown and will vary depending on the condition of the straw initially. However, favourable results have been attained anywhere from 7 to 14 days.

Wetting: The amount of time flax straw remains wet was closely linked with the time it took for it to ret. In the previous paragraph where retting time is discussed, it is the time the straw was wet that was meant. However, there are also the dynamics of wetting interval and duration.

For the majority of the tests performed, the wetting interval was such that it maintained moisture at a level where droplets were still visible on the individual straws, and the straw mat was wet to the touch. Initial tests explored the idea of stretching intervals between wetting to reduce water usage, but it was found that if too long, retting came to a standstill. It was determined that keeping the straw mat wet was crucial to the process.

Wetting duration was also determined along the same guidelines. As straw moisture seemed to be integral to inducing and sustaining retting conditions, the duration of the wetting cycle was adjusted to ensure the straw was exposed to water. For the tests involving sprinkling systems, this meant allowing enough time to pump an adequate volume for sufficient coverage. For the trials utilizing a dipping period, the duration was adjusted to permit penetration of the straw mat or bale.

Drying

Time as it concerns drying has the inverse effect on retting that wetting did. Inserting a drying cycle into the process brings retting to a halt, at least temporarily. This can be observed in **Table 12**.

Table 12. Comparison of Test 5 Retting Results.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 5	After II - 2 Days Wet/Dry/2 Days Wet	0.77	94.9%
Test 5	After III - 4 Days Wet	1.02	73.6%

Although both samples were each wet for four days, they did not produce similar results. Adding the overnight drying time to the After II sample inhibited the retting process. Whereas, the After III sample, which was allowed to ret uninterrupted for four days, achieved more complete retting. Test 5 results exemplify best what effect a drying cycle can have, but the same results are also found in some of the initial tests (Test 0). Whenever the straw became too dry, through too long a delay between wetting intervals or air movement, retting did not proceed at the pace it normally would have had it been sufficiently wet.

The other effect drying had on the retting process was the introduction of an opportunity for mould to grow. The tests performed appeared to indicate that drying affected mould growth both ways. It was responsible for establishing mould growth as the straw dried but also arrested its development as it dried further. Mould seemed to establish in the interval between wet enough to ret and too dry to ret. There appeared to be a certain moisture level at which the mould best thrived. This was evident in a number of tests. For instance, in the early tests (Test 0) involving humidity, mould appeared relatively quickly. This coincided with the straw drying out beyond a level at which retting could progress. However, the high RH conditions were not dry enough to terminate the mould cycle. This was also apparent in Test 9, as the uneven water distribution and excessive interval between wettings allowed mould to invade the bale. It is notable that in the many other tests in which moisture levels were maintained adequately, mould was not a problem. The same is true of dry, unretted straw.

Using a forced-air drying interval to stop the retting process was found to be quite effective. Loose straw, as opposed to straw in a bale, was successfully dried using aeration fans in a matter of hours. Samples on the small-scale box were often dried within two hours, and the batches (approximately 41 kg) on the large-scale trailer were easily dried within 15 to 18 hours. In the baled form, the straw took much longer to dry

with the use of forced air. To completely dry, the straw required up to six days and wrapping the bale in tarps to force the air down through it, instead of being pulled in from the sides. Presumably, as in grain drying, using hot air to supplement the drying cycle would decrease the drying time.

2.5.3 Humidity

The use of humidity to supply the moisture required to sustain retting was generally found to be ineffective. Relative humidity of 80% and 90% were evaluated. Although humidity managed to add to the moisture content of the straw, which was noticeable in the flexibility and pliability of the straw, it did not maintain surface moisture. All of the subsequent testing pointed to the importance of keeping the straw wet in order to facilitate retting.

Efforts were made to relocate the moisture from the air to the straw, through the use of air circulation. It was thought that drawing the moist air through the straw would allow the water to be wicked away by the straw. This had the opposite effect; however, drawing the straw's moisture out and effectively stopping retting. This effect is evident when looking at the sample 90% RH Tube 7 days in **Table 13**.

Table 13. Comparison of Forced Air Effect in Test 0.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 0	90% RH Initial Tube	1.07	65.2%
Test 0	**90% RH Tube 7 days**	**1.44**	**46.8%**
Test 0	80%/90% RH - initial	0.67	55.4%
Test 0	80% RH 7days - #2	2.13	31.0%
Test 0	80% RH 7days - #5	1.80	37.6%
Test 0	90% RH 8 days - #1	1.63	45.9%
Test 0	90% RH 8 days - #4	1.50	54.6%

In the seven days using forced air circulation, the 90% RH Tube 7 days sample only managed to further retting about 12.5%. In relatively the same period (seven to eight days), the samples without air movement averaged 43% (80% RH) and 30% (90% RH) increases in retting above the initial sample.

2.5.4 Temperature

Temperature was found to be a minor factor for retting. Within a certain range of temperatures, barring extremes at either end, it was discovered that temperature did not regulate the starting or stopping of the retting process anywhere near the effect as wetting and drying. Although not dramatic, adjusting temperature did prove to assist in optimizing retting conditions, as Test 8 determined.

Table 14. Comparison of Day 7 Retting Results from Test 7 and 8.

Test #	Sample	Level of Retting (0.0-3.0)	% Difference in cv
Test 6	Before	0.17	198.3%
Test 7	Sample I (Day 7)	1.07	76.6%
Test 8	Day 7 (35°C)	1.70	40.6%

Comparing the Day 7 results for Test 7 and 8 indicates that with favourable temperature conditions, retting progresses further. Maintaining temperature to provide an environment for the microbes of 35°C is suggested to be ideal. However, conditions greater than 40°C would negatively impact the microbial population, eventually slowing or halting retting. The same would likely be true of colder temperatures. The impact of extreme temperatures was noted in Test 9 in which retting appeared to pause. Ambient temperature goals of 35°C were being met, but the microenvironment inhabited by the microbes (inside the bale) was greater than 40°C. Retting was temporarily stopped until the temperature was reduced to a level suitable for the population's survival.

2.5.5 Water Utilization

Some of the later tests involved efforts to quantify the amount of water required for retting. Earlier tests measured the water flow rate and timed the application. Later tests weighed the straw, initially dry and then wet, to ascertain water volume through mass changes. In some cases, a water meter was used to monitor the water added to the straw.

Through the mass measurements taken, specifics of water volume were calculated. On average the water volume topped out around 2.7 L/kg of straw. This of course varied depending on how recent the last wetting interval had been. In practicality, this number dipped as low as 0.5 L/kg of straw. However, in retrospect, this did help to explain some end results from the different tests.

In the tests where retting appeared to progress at an acceptable pace, the average volume of water throughout the testing period settled around 2.0 L/kg of straw. In Test 9, in which retting was the most irregular, the water volume averaged 0.8 L/kg of straw. Comparison of the water in use per kg is displayed in **Figure 7**.

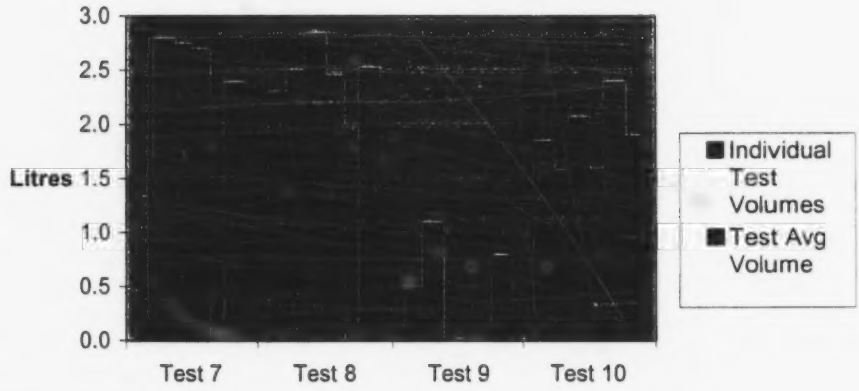

Figure 7. Comparison of Water in Use per Kg of Straw by Test.

Obviously, much less water was in use and available to assist in the retting process for Test 9. This may explain the mould present and inconsistent retting throughout the bale in this test.

Although these numbers aid in understanding retting water utilization in relative terms, they do not quantify volume in absolute terms. They do not consider the total water requirement from start to finish of the process. Many factors will affect this volume. These include the losses to the system, temperature, relative humidity, and even process method.

Water losses to the system are largely unaccounted. Losses are expected in the form of evaporation from the straw mass, but to what degree? Clearly, water will be absorbed from the straw by the surrounding air, however, whether it is completely lost from the system or just temporarily unavailable is questionable. The amount evaporated is also subject to the temperature and humidity conditions – warmer, lower RH conditions would induce more evaporation.

In some of the tests performed, the volume of water supplemented during testing was monitored. This water added to the tests was to replace water lost to evaporation and spillage. The amount varied widely from 255 to 436 L. This variation is due in large part to the variability in test design and procedures but also to the factors mentioned in the previous paragraph. For this reason, the numbers due not strictly or accurately represent water losses or supplemental requirements.

As mentioned previously, the procedure utilized for retting will also drastically impact water use. The amount of water actually being used to ret the straw at any given time does not completely reflect the total requirement. A certain amount of surplus needs to be in place to allow for charging of the pumping system or sufficient volume for submersion. Procedural water demands will be higher or lower depending on method of application (sprayed or dipped).

2.5.6 Whole Round Bale

Retting a whole round bale presented a new dimension not seen before on the smaller scaled tests undertaken on the test bed. That dimension being the role that straw mat density played in the process. In the smaller scaled tests, the density of the straw mat was unaccounted for and did not have any consequences on the success of retting. In a round bale, however, its influence was notable.

Density of the layers in the bale controlled the distribution of water throughout the straw mass and hence the retting process. The layers limited straw exposure to water, channelling it through, allowing some sections to absorb, and depriving other areas completely. This made for erratic retting. Beyond the channelling effect of the layers, straw density also affected the permeability of the straw mat, regulating infiltration and absorption.

The other dynamic the round bale added to the equation, was the insulating effect produced by the straw layers. This was notable in Test 9 in which the internal bale temperature exceeded the ambient temperature by several degrees. The bale layers served as insulation, trapping the heat generated by the microorganisms inside. Eventually, the retting process suspended, presumably due to microbial mortality. Ambient temperature had to be lowered to account for the insulating function the straw provided, essentially to prevent the bale from becoming to warm.

2.5.7 Full Scale Plant

At this juncture, speculating on costs, or even procedure, for full-scale flax straw retting plant would be premature. Many of the trends and variables of flax straw retting are better understood due to the tests done, but still too many of the details are yet to be determined. Additional research is required yet to ascertain the particulars of the retting process, start to finish.

It has been revealed that time is a crucial element involved in retting; however, as of yet a precise timeline has not been established. Research has suggested that to complete, 7 to 14 days is required. Efforts to condense the process into a shorter time span (3 to 7 days), yielded incomplete results, although retting appeared to be well underway.

Process time will vary depending on the state of the straw initially, and the parameters of the retting methods used. It is also important to note that using a drying interval upon completion to halt retting will add to overall process time.

Another unanswered variable is whether retting can be performed to completion at a full-scale level. The results of Test 10 suggest that retting is possible in the form of a whole round bale. It did not, however, define how long it would take to finish. Also, it was not evident whether any consistency or regularity could be achieved in the level of retting. At this time it would seem that with some fine-tuning, favourable results should be attainable.

The question of using round bales is just one of the unknowns in the formula. There are many other factors in establishing a full-scale plant that would need to be addressed. For instance, what type of process would be implemented, batch or continuous? This of course would depend on other procedural elements, such as the use of loose or baled straw, whether it was dipped in or sprayed with water, and if it was to be subjected to a forced-air drying interval upon completion.

In deciding what procedure to use, consideration must also be given to the water required. Conditions of the water must be such that it is not harmful to the micro fauna involved in retting. This involves adjustments to pH, but it may also require attention to other factors such as water hardness to optimize the process. Dependent on the procedure, wastewater must also be addressed. If water can be recycled and evaporation losses supplemented with fresh water for subsequent rettings, disposal may not be an issue. In this case, there may be no effluent, as evaporation might be the only exit from the system. However, wastewater disposal might become a larger matter in the case of a more open loop system, especially if there are environmental concerns attached to it.

For water, another consideration is the volume required. These tests did not produce any definite numbers as to volume. Indication of requirements for individual tests was observed, however, extrapolating that to full-scale is difficult. This is especially true in the case where other variables (batch or continuous, soaked or sprayed) are undetermined.

Of course there are many other facets that deserve consideration when converting any test procedure to full scale. These may include things that were not even contemplated for the purposes of this project. For instance, treatments prior to the retting process like mechanical processing (i.e. decorticating) might prove to be useful. Also, the age of the straw being retted, and if it is in bale form, whether it is hard-core, soft-core, or square, might be shown to have an impact. Other things like water or air movement could be monitored and controlled to gauge retting response. Photosensitivity and the effects of

light or ultraviolet treatments could be significant. Post-process dynamics include odour assessment and realizing opportunities for mutually beneficial companion industries. Also, consideration would need to be given to the air quality in a plant environment, as the potential for mould growth exists when organic matter and water are combined in warm temperatures. While not necessarily harmful, the moulds may cause irritation for some people.

All of these aspects, and presumably many others, facilitate the need for further research to better define the parameters involved in flax straw retting before a full-scale plant is designed and implemented.

3. Personnel

3.1 PAMI Manpower Supplied

It is PAMI's policy to charge rates that include salary and benefits of employees as well as overhead. These charge rates do not include profits and to ensure that overhead is not charged to the project, indirect services, management time and use of PAMI equipment are provided at no cost. It has been calculated that this adjustment removes more than overhead costs from actual charge rates. It is PAMI's policy not to release individual salary information.

Professional

- Philip Leduc
- James Wassermann
- Darrell Lischynski
- Gordon Hultgreen
- Les Hill
- Troy Lucyshyn

Technical

- Nathan Gregg
- Nelson Klapak
- Pete Koski
- Murray Cook
- Ted Bay
- Andrew Rauert
- Wayne Stock
- Greg Burton
- Mark Ingram
- Derek Rude

Support Personnel

- Errol Cross
- Gordon Doepker
- Rachel Abrey
- Shelly Stroeder
- Laurie Szautner

5. Equipment

No equipment was purchased for this project.

6. Project Photos

Project photos are contained in the body of this report.